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CO-GASIFICATION OF COAL WITH BIOMASS AND PETCOKE IN A HIGH-PRESSURE GASIFIER FOR SYNGAS PRODUCTION

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Abstract

Co-gasification experiments of binary (coal – biomass) and ternary (coal – petcoke – biomass) blends were conducted in a novel pressurized gasifier to study possible synergetic effects. Interactions between the blend components that modified the gas production were observed. An improvement in syngas production and cold gas efficiency was attained when coal was gasified with biomass.

Keywords: biomass, co-gasification, syngas, high-pressure

INTRODUCTION

Co-gasification of biomass with coal is considered as a bridge between the energy production systems based on fossil fuels and those based on renewable energy sources. It could contribute to reduce the fossil fuels dependency and CO_2 emissions, as biomass is known to be neutral as regards CO_2 emissions. The high reactivity of biomass and its high volatiles content, suggest that some synergetic effects might occur in simultaneous thermochemical treatment of coal and biomass, depending on the gasification conditions such as: reactor type, feedstock type, pressure, temperature, etc. [1].

Currently, co-gasification of coal and biomass is conducted at IGCC electricity generating power plants such as ELCOGAS, which is the world's largest IGCC facility using coal and petcoke as feedstock, located in Puertollano (Spain), where there is an ongoing project aimed at evaluating the effects of adding small percentages of biomass, up to a maximum amount of 10 wt.% on the performance of the plant [2].

In this work, co-gasification experiments of binary (coal – biomass) and ternary (coal – petcoke – biomass) blends were carried out to study the effect of blending different nature fuels. For this purpose, a novel pressurized fixed bed gasifier, using steam/oxygen mixtures as gasifying agent, provided with a solid feeding system in a continuous mode was used.

EXPERIMENTAL

In this work, a bituminous coal (PT), a petcoke (PC), and three types of biomass: almond shells (AS), olive stones (OS) and pine sawdust (PS) were used. The samples were ground and sieved to obtain a fraction with a particle size of 75-150 μm. The proximate and ultimate analyses and the high heating value of the samples are presented in Table 1.

Table 1. Proximate and ultimate analyses and high heating values of the samples

Sample	Proximate Analysis (wt.%, db)		Ultimate Analysis (wt.%, daf)					HHV (MJ kg^{-1})
	Ash	V.M.	C	H	N	S	O*	
PT	36.3	24.7	71.2	4.8	1.5	1.7	20.8	29.1
PC	0.3	9.6	87.6	3.8	1.5	6.2	0.9	35.1
AS	1.2	79.3	49.8	6.1	0.2	0.0	43.9	19.9
OS	0.8	83.8	52.0	6.2	0.1	0.0	41.7	20.4
PS	1.4	86.5	49.8	6.6	0.2	0.0	43.4	20.2

dry basis (db); dry ash free basis (daf); * calculated by difference

The experimental device used for the gasification tests has been described in detail in a previous work [3]. Briefly, it consists of a stainless steel tubular reactor with a porous plate, which is able to work at a maximum pressure of 20 atm at 1000 ºC. Fuel particles are fed continuously into the system from a pressurized hopper, which ensures a steady gas production. The gasification tests were carried out isothermally at a constant pressure of 15 atm, using as gasifying agents a mixture of steam and oxygen, carried in an inert flow of N_2, , at a total flow rate of 200 Ncm^3 min^{-1}. The composition of the dried gases (H_2, O_2, N_2, CO, CH_4 and CO_2) was analysed on line, using a micro-GC. The amount of

gas generated during the experiments was calculated from a nitrogen balance, since the amount of nitrogen fed in and the composition of the nitrogen evolved are known. The experimental error margin was evaluated by calculating the errors produced in the gas composition from repeating an experiment several times on different days. The values obtained were lower than 4%.

RESULTS AND DISCUSSION

Gasification tests of binary blends of coal PT combined with different biomass samples (AS, EB and OS), as well as ternary blends (PT-PC-Biomass) were carried out. For this purpose, the feed mass flow rate was set to maintain the values of the O/C and H_2O/C constant.

a) PT – Biomass blends

Figure 1 shows the production of the main gases during the co-gasification of binary blends of coal PT and biomass (950 ºC, 15 atm, 5 and 55 vol.% of O_2 and H_2O_v, respectively). This figure shows that H_2 production and, especially, that of CO, increased with additions of up to 10 wt.% biomass. A certain increase in gas production could be predictable, as biomass fuels are much more reactive than coal, leading to a higher amount of syngas produced. However, the increase in the gases production seems to be really significant taking into account the low percentage of biomass used.

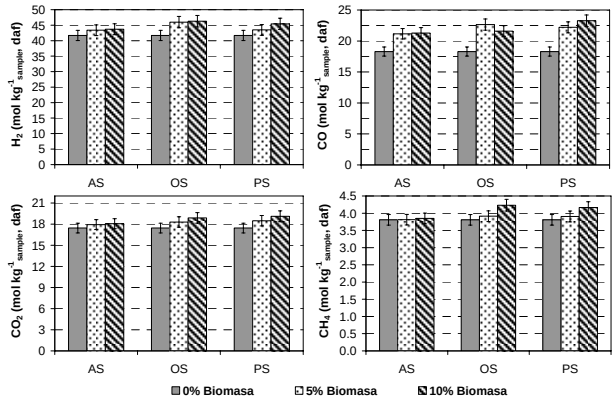

Figure 1. Main gases production during high-pressure co-gasification of binary blends of PT-Biomass (950 ºC, 15 atm, 5 vol.% O_2 and 55 vol.% H_2O_v).

Table 2 summarises the main gasification parameters of PT-biomass binary blends. It can be observed that carbon conversion, *X*, of the coal-biomass blends was higher than that corresponding to the gasification of the individual coal. If interactions between fuels did not take place, and assuming that biomass reacts completely, the maximum carbon conversions that would be expected, based on coal carbon conversion, would be 64.6 and 66.4 % for blends with biomass percentages of 5 and 10 wt.%, respectively. Nevertheless, the experimental results showed that the obtained values were between 7.3 and 10 % higher than the theoretical values, indicating the existence of interactions between coal and biomass fuels that led to a rise in coal carbon conversion [4].

Table 2. Gasification parameters of binary blends of coal PT with biomass (950 ºC, 15 atm, 55 vol.% H_2O_v and 5 vol.% O_2)

Blend	PT	PT-AS		PT-OS		PT-PS	
Biomass (wt.%)	0	5	10	5	10	5	10
H_2/CO	2.3	2.0	2.1	2.0	2.1	2.0	2.0
CO/CO_2	1.0	1.2	1.2	1.2	1.1	1.2	1.2
Yg ($Nm^3\,kg^{-1}$)	2.07	2.22	2.33	2.28	2.31	2.19	2.34
HHV (kJ Nm^{-3})	6223	6363	6276	6554	6677	6559	6614
η (%)	69.0	75.2	77.7	79.5	81.6	76.6	82.3
X (%)	62.7	69.2	70.9	72.3	73.2	71.9	76.4

In Table 2 it can also be observed a slight decrease in H_2/CO ratio, as the increase in the H_2 concentration was lower than that of CO [5,6]. In addition, an increase in cold gas efficiency, η, was attained due to the higher gas yield, Y_g, and its higher high heating value, *HHV* [6,7]. Interactions that take place between coal and biomass could be due to the high reactivity of the biomass fuels. When coal is fed to the reactor with biomass, the latter will react rapidly, releasing a high amount of volatile matter by thermal or oxidative cleavage of the weakest covalent bonds in the organic matter, which readily decompose and form plenty of free radicals, which react not only with biomass organic matter, but might also react with coal, thus promoting the decomposition and the oxidation and gasification reactions in coal. But also, the hydrogen-rich light molecules produced from the biomass devolatilisation and volatiles cracking, might react with the volatiles produced form coal, thus avoiding the recombination reactions and the formation of less reactive secondary char [4]. In addition, the alkali metals presented in the mineral matter of biomass fuels, such as Na, K and Ca, might also favour the heterogeneous gasification reactions of coal [8].

b) PT – PC – Biomass blends

Different types of biomass were added to a 50-50 wt.% binary blend of coal PT and petcoke PC. Figure 2 presents the main gases production during the

gasification of ternary blends of PT – PC – Biomass (45-45-10 wt.%) (1000 ºC, 15 atm, 5 and 55 vol.% of O_2 and H_2O_v, respectively).

In this figure it can be appreciated that the H_2 production obtained during gasification of the binary blend PT-PC was almost not affected by substituting 10 wt.% of fuel by biomass. However, a slight decrease in CO production to the time that CO_2 production increased, were observed.

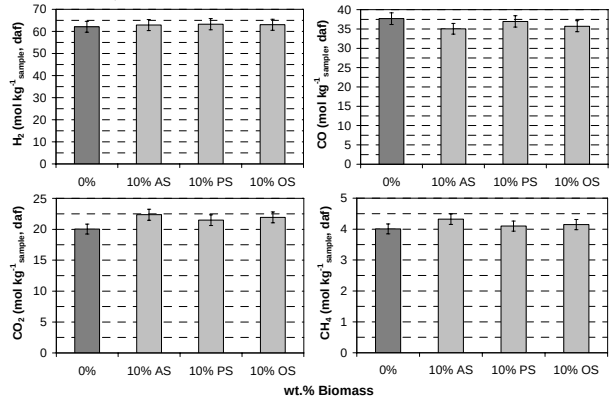

Figure 2. Main gases production during high-pressure co-gasification of ternary blends of PT-PC-Biomass (1000 ºC, 15 atm, 5 vol.% O_2 and 55 vol.% H_2O_v).

These results seem to indicate a lower interaction degree between the biomass and the PT – PC blend. From Table 3, where the main gasification parameters of ternary blends are summarized, it can be observed that when biomass was added to the fossil fuels blend, an increase in the gas yield was produced. These results led to a gas with a higher *η*, although the *HHV* of the gas produced from ternary blends was lower than that produced from the binary fossil fuels blend (PT-PC), mainly due to the higher CO_2 production.

Table 3. Gasification parameters of ternary blends PT-PC-Biomass (45%-45%-10%) (1000 ºC, 15 atm, 55 vol.% H_2O_v and 5 vol.% O_2)

Sample	PT-PC	PT-PC-AS	PT-PC-OS	PT-PC-PS
Composition (wt.%)	50-50	45-45-10	45-45-10	45-45-10
H_2/CO	1.6	1.8	1.8	1.7
CO/CO_2	1.9	1.6	1.6	1.7
Yg (Nm^3 kg^{-1})	3.66	3.91	4.03	3.98
HHV (kJ Nm^{-3})	7132	6779	6588	6752
η (%)	97.7	101.7	101.8	103.0
X (%)	93.3	96.9	96.7	98.2

With respect to the carbon conversion, similar effects than those obtained during binary blends gasification, although in a lower extent, were obtained. This behaviour was mainly due to the fact that the maximum *X* that would be expected to reach during ternary blends gasification, considering 100% biomass conversion, would be 94%, whereas an increase in more than 3% was obtained. In the case of ternary blends, biomass seems to exert a lower effect on gas production and the other process parameters. This could be due to the fact that PT-PC blend has a different behaviour than that of coal separately [3]. As it was previously said, in the case of PT-Biomass blends, the most reactive component can undergo a partial oxidation leading to a rise in the CO production. However, in the case of ternary blends, the oxygen availability in the devolatilisation reactor zone is higher, since in this case, petcoke, which releases a small amount of volatile matter, is also fed. Thus, volatile matter released by biomass can be more easily oxidized, and leading to a lower free radicals formation; so the latter, would interact in a lower extension with the lower amount of volatiles released by PT-PC blend.

In sum, it can be said that under the conditions used in this work when fuels with very different reactivities (coal, petcoke, biomass, etc.) are gasified as a blend, synergetic effects may take place due to volatile – volatile and volatile – char interactions, and possibly to mineral matter catalytic effects, leading to an increase in conversion and producing higher cold gas efficiencies.

CONCLUSIONS

In this work, co-gasification experiments of binary (PT – Biomass) and ternary (PT – PC – Biomass) blends revealed the existence of interactions between their components, which modified the gas production under the experimental conditions used. The addition of a small amount of biomass (up to 10 wt.%) to coal, led to an increase in syngas production, giving rise to an increase in cold gas efficiency, and therefore, in carbon conversion. Likewise, the presence of biomass in the PT-PC blend led to an improvement in carbon conversion and cold gas efficiency.

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